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Project Summary

Evaluation of a Treatment Lagoon for Combined Sewer Overflow

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Results are summarized of a 2-year study to assess the effectiveness of the world's largest facultative lagoon for treating combined sewer overflow and the polishing effluent from a secondary wastewater treatment plant. The project was divided into five different activities, each of which evaluated a different aspect of the overall treatment scheme.

The first activity was to determine the physical characteristics of the lagoon (size, aerator locations, and influent and effluent discharge levels). Second, lagoon performance was evaluated for changes in the degree of aeration, which has the dual function of mixing the lagoon and increasing the oxygen levels above those provided by natural reaeration. Third, the pollutant removal performance of the lagoon was evaluated for different discharge levels and detention periods. Removal efficiencies were determined by daily sampling of the influent and effluent and of water at several locations within the lagoon. Fourth, the effects of the stormwater loadings on lagoon performance were assessed to determine the buffering capacity of the lagoon for treating volumes of highly polluted, intermittent flow. Fifth, full-scale application of sequential chlorine and chlorine dioxide disinfection was evaluated.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The East Chicago Sanitary District (ECSD) operates a wastewater treatment plant that handles about 19 mgd* of dry weather municipal wastewater from the city of East Chicago, Indiana. This wastewater includes industrial discharges. Secondary treatment consists of a conventional activated sludge process. The East Chicago sewerage system has combined sewers with overflows containing both direct industrial discharges and runoff from industrial areas. Bacterial contamination of the Grand Calumet River has occurred in the past as a result of combined sewer overflows (CSO).

In the late 1960's, the ECSD received a demonstration grant to construct and evaluate the world's largest facultative lagoon. The facility was intended to polish the secondary effluent from the wastewater treatment plant (WWTP) and to provide preliminary treatment with disinfection to the combined sewer overflows. The project was to demonstrate the feasibility of this technique for dual CSO treatment and secondary effluent polishing at an industrial urban area.

The city's objective was to meet the state, regional, and federal water

*To convert mgd to m^3/s, multiply by 0.044.

quality requirements for the Grand Calumet River by improving the quality of effluent from the East Chicago wastewater treatment plant and overflows from the Magoun Avenue pumping station. Interception of the combined sewer overflows prevents discharge of raw wastewater into the Grand Calumet River, thus eliminating excessive bacterial levels after storms and providing improvement in other respects. The improved quality of the Grand Calumet River Basin and of the lower reaches of Lake Michigan will enable increased industrial and recreational use of these waters. The value of the project to the federal water program was to demonstrate a proven wastewater treatment approach for handling combined sewer overflows.

Physical Characteristics of the Lagoon and Related Appurtenances

Construction of the East Chicago treatment lagoon began in 1969 and was completed in 1971. During construction, several actions were undertaken that resulted in substantial changes from the original design. The original lagoon design specified a 700- by 900-ft basin with levee sides and a maximum water depth of 40 ft. Field surveys indicated that the post-construction lagoon surface area remained unchanged, but that the water depth was considerably less than that originally planned. Depth readings were measured throughout the lagoon. Readings within 15 m (50 ft) of the shore on any side reflected the 2 to 1 slope of the levee sides. Depths throughout the remainder of the basin ranged from 7.62 to 9.75 m (25 to 32 ft), with an overall average of 9.1 m (30.1 ft). Volume of the post-construction lagoon is estimated to be 142.2 million gal.

Final construction of the influent system included a 9-ft-wide by 8-ft-high concrete channel along the north side, with final discharge through a 48-in. conduit. Original intentions were that the influent be controlled by means of four outlets from the influent channel, with a combined capabililty of handling the entire Magoun Avenue Pumping Station flow of 178 mgd. The capacity of the single 48-in. conduit is insufficient to handle the combined sewer overflow (CSO) and overflow of the influent spillway during major storms.

The lagoon effluent mechanism was to have incorporated four controlled outlets feeding a concrete channel within the south levee. A concrete apron corner with a dry weather flow channel was substituted for the original system. Currently, no means exist for directly controlling lagoon inflow and outflow. Influent enters the lagoon at a single point source and is directly related to pump rates. Effluent rates are directly related to lagoon water surface levels and discharges from a single point.

Aerators

Depth of the detention basin was designed to allow partial oxygen depletion, yielding aerobic surface treatment with anaerobic bottom waters. The depth of the aerobic layer is controlled by eight surface aerators. The aerators are single speed, 50-hp, electically driven units with waterproof cables connecting the units to onshore power transformers. No guards are provided to protect the upper section from induced spray, nor is there any mechanism to manipulate the area of inflow to limit deep water draw.

Pumping Stations

During rainly periods, CSO from 20 percent of East Chicago reaches the Magoun Avenue Pumping Station and is pumped into the lagoon. Before lagoon construction, CSO from this station was pumped directly to the Grand Calumet River.

A dry-weather flow lift station was incorporated into the original facility design to pump all the wastewater treated at the East Chicago secondary plant to the lagoon. Three fixed-speed pumps were installed within the lift station. Two were capable of pumping 8 mgd each to the lagoon, and the third unit had the capacity to pump 3 mgd.

Dry-Weather Lagoon Performance

The lagoon evaluation period of 56 weeks was divided into several phases based on prevalent influent rates to the lagoon. Six weeks were without any inflow. The influent rate was 3 mgd for 33 weeks. Fifteen weeks of evaluation were conducted at an influent rate of 18.8 mgd, which is the maximum inflow rate provided by all three pumps. The final 2 weeks of the evaluation program were conducted at a reduced flow rate of 11.3 mgd. Flows were reduced during this period to help evaluate the effects of detention time on lagoon performance.

Pollutant loadings into the lagoon were a function of the East Chicago WWTP flow rate and the concentrations of individual constituents within the treatment plant effluent. Influent to the lagoon was controlled on a volume basis by the operation of the lift pumps. Concentrations of wastewater constituents were mainly a function of the degree of treatment provided by the secondary plant. Because of the combined effects of erratic influent pollutional loads and variable treatment efficiency, the treatment plant effluent concentrations varied widely.

Statistical reduction of the lagoon performance data are shown in Tables 1, 2, and 3 for the three evaluation periods. Except for organic pollutants, the influent concentrations were reasonably consistent over the three evaluation periods. The organic contaminant increases during the low-flow period could have been due to seasonal changes, since the cold weather may have reduced treatment plant effectiveness.

The average pollutant removals for the three flow rates are summarized in Table 4. Effluent concentrations are listed as averages of the flow period. Percentage removals for each flow rate were determined using the average influent and effluent concentrations. Also listed are the overall removal efficiencies considered bypasses when the secondary effluent exceeds the pumpage rate of 11.3 mgd. No flows are bypassed at a pumpage rate of 18.8 mgd.

The results listed in Table 4 were expected, considering the nature of difficulties encountered with the lagoon's operation. Little aeration was provided during most of the 3-mgd flow period. Although long detention periods were theoretically possible during this period, severe short-circuiting of influent flow effectively minimized the actual treatment time. Lagoon removal efficiencies for the 11.3 mgd flow rate were higher than those computed at the higher rate of 18.8 mgd.) This result was expected, since a theoretical detention time of 12 days is possible at 11.3 mgd, but only 7 days of detention are provided at 18.8 mgd. Aeration/dye tracer studies have

Table 1. *Summary of lagoon performance at an influent rate of 0.13 m^3/s (3 mgd)**

	Influent				Effluent			
Parameter	Mean conc. (mg/l)	No. of samples	Std. dev.	Coeff. var (%)	Mean conc. (mg/l)	No. of samples	Std. dev.	Coeff. var (%)
BOD_u	36	1	--	--	17	69	13.9	82
BOD_5	44	28	33.4	76	30	28	29.5	105
COD	155	60	49.5	32	83	60	30.1	36
TOC	47	81	45	96	28	81	10.9	39
TSS	168	71	267	159	35	71	23	66
VSS	75	68	110	147	24	68	20	83
TS	1585	52	757	48	1365	62	579	50
NO_3	---	---	---	---	---	---	---	---
TP	1.30	52	1.49	115	57	62	.80	140
Turbidity†	80	78	51	64	40	78	10	25

* Test period covered August 1978 to April 1979.
† Turbidity values in JTU.

Table 2. *Summary of lagoon performance at an influent rate of 0.49 m^3/s (11.3 mgd)**

	Influent				Effluent			
Parameter	Mean conc. (mg/l)	No. of Samples	Std. dev.	Coeff. var (%)	Mean conc. (mg/l)	No. of Samples	Std. dev.	Coeff. var (%)
BOD_u	21.	12	11.	92	22.	12	8.5	37
BOD_5	23.	12	17.3	75	13.	12	8.3	64
COD	117.	14	112	96	57.	14	19.	33
TOC	39.	12	10.7	27	26.	12	5.7	22
TSS	230.	15	407.	177	16.	15	6.6	41
VSS	68.	15	79.	116	9.	15	5.3	59
TS	1639.	15	370.	23	1323.	15	201.0	15
NO_3	6.3	15	3.7	59	6.1	15	4.7	77
TP	1.13	14	.67	59	.23	14	.12	52
Turbidity†	113.	13	61.	54	21.	13	10.7	51

* Test period covered August to September 1979.
† Turbidity values in JTU.

Table 3. *Summary of lagoon performance at an influent rate of 0.82 m³/s (18.8 mgd)**

Parameter	Influent				Effluent			
	Mean conc. (mg/l)	No. of samples	Std. dev.	Coeff. var. (%)	Mean conc. (mg/l)	No. of samples	Std. dev.	Coeff. var. (%)
BOD_u	18.	17	8.8	49	26.	19	18.5	71
BOD_5	22.	17	10.3	47	21.	19	18.5	88
COD	120.	1	--	--	79.	23	34.7	44
TOC	40.	23	17.0	42	28.	23	9.6	34
TSS	144.	25	147.	102	32.	25	11.4	36
VSS	60.	25	51.	85	21.	25	9.0	43
TS	1626.	25	333.	20	1571.	1	--	
NO_3	5.5	1	--	--	5.5	1	--	
TP	1.24	23	.72	58	.34	23	.22	65
Turbidity†	83.	22	54.	65	21.	23	9.6	42

* Test period covered May to August 1979.
† Turbidity values in JTU.

Table 4. *Summary of average pollutant removal efficiencies for three influent flow rates.*

Parameter	0.13 m³/s (3 mgd)			0.49 m³/s (11.3 mgd)			0.82 m³/s (18.8 mgd)			
	Influent* (mg/l)	Effluent* (mg/l)	Removal (%)	Influent* (mg/l)	Effluent* (mg/l)	Removal (%)	Influent (mg/l)	Effluent* (mg/l)	Removal (%)	Overall Removal† (%)
BOD_u	36.	17.	53	21.	22.	--	18.	26.	--	--
BOD_5	44.	30.	32	23.	12.7	45	22.	21.	4	27
COD	155.	83.	46	117.	57.	51	120.	79.	34	31
TOC	47.	28.	42	38.6	25.9	33	40.	28.	31	20
TSS	168.	35.	79	230.	16.	93	144.	32.	78	56
VSS	75.	24.	68	68.	9.	86	60.	21.	65	52
TS	1585.	1365.	14	1639.	1323.	19	1626.	1571.	3	11
NO_3	--	--	--	6.3	6.1	3	5.5	5.5	0	2
TP	1.3	.57	56	1.13	.23	80	1.24	.34	73	48
Turbidity	80.	40.	49	113.	21.	91	83.	21.	75	55

* Mean concentrations.
† Overall removal at 0.49 m³/s (11.3 mgd) rate, considering untreated bypassed flows.

shown that even with the limited aeration provided during evaluation at these flow rates, nearly complete lagoon mixing occurred. Influent pollutant concentrations were quite similar and temperature variations were minimal, thereby eliminating the possible effects of these variables.

Based on the overall removal rate (including bypasses), the higher inflow rate of 18.8 mgd is considered optimum. At the 11.3 mgd pumping rate, excess secondary treatment plant effluent is discharged to the river without further treatment. The removal rates at the 11.3-mgd flow rate are less than those at the 18.8-mgd rate, with the exceptions of BOD, total solids (TS), and NO_3. The NO_3 removals are low in both situations. The TS and BOD removals were impaired by four storm events during the higher flow period. These occurrences caused pollutant washout from the WWTP that resulted in high residual loadings to the lagoon.

Limited removal of TS during both flow periods resulted from the poor settling of fine particles. Although suspended solids (SS) removals were high, these loadings represent only a small fraction of the TS load. The results suggest that the settling velocities of the fine solid particulates are insufficient to overcome lagoon currents and scouring near aerators. This problem was further complicated by the high occurrence of aerator failures. Quiescent settling zones near nonoperational units developed, and upon restart, bottom scouring occurred often, and to the extent that the surrounding surface waters became visually black.

Wet-Weather Lagoon Performance

Assessment of lagoon performance for storm events is extremely difficult. First, the pumped effluent from the wastewater treatment plant varied so much that any estimate of dry-weather loadings would have been subject to considerable error. Second, the automatic samplers monitoring both the influent and effluent were prone to mechanical malfunctions, resulting in incomplete representations of storm events. Third, the wet-weather events were never totally monitored, since the washout period was always substantially longer than the period during which the samplers were in operation. The average removals for the three storm events approximated the removal rates during dry-weather flow.

Aeration Studies

Lagoon Mixing and Flow Characteristics for Various Aeration Schemes

Lagoon flow patterns are determined by the rate of inflow into the lagoon and by the number and locations of aerators in operation. The lagoon was originally designed to contain nine equally spaced aerators. The current configuration includes eight irregularly spaced units. Random down time of the units resulted in numerous combinations of aerators in operation during the lagoon evaluation period. Lagoon flow and mixing patterns could not be directly assessed for all such combinations. Several studies were performed to ascertain the effects of aeration on lagoon flow patterns. Documentation of short-circuiting and limited detention times was needed for data reduction and analysis.

Dye studies performed under several of these conditions demonstrated the general trend of induced flow patterns. Influent discharge from the 48-in. feed line tended to flow directly across the lagoon. The extent of the immediate flow across the lagoon was a function of initial influent momentum and thus flow rate. As expected, higher flow rates extended the flows further across the lagoon. Without aeration, lagoon flow patterns allowed limited mixing of the interlagoon waters, with most of the inflow rising to the surface and flowing to the effluent spillway with minimal detention time and limited treatment.

Evaluation of the mixing characteristics of a single aerator indicated that each unit was capable of influencing lagoon water flow patterns to a distance of more than 100 ft. Aerators create flow patterns that extend to the lagoon bottom near the units. Flow patterns generally moved toward the aerators at depths below 10 ft and away from the aerators above this depth. Water velocity generally decreased with distance from the aerator and with depth.

With the aerators in operation, the lagoon waters were adequately mixed with the influent. Operation of all eight aerators mixed the lagoon completely, producing high removal rates at optimum detention times. Analysis later indicated that only four aerators were required to mix the lagoon completely. Each 50-hp surface aerator effectively mixed 35 mil gal indicating a requirement of 1.3 hp/mil gal in a water body approximately 30 ft deep.

Lagoon Performance With and Without Aeration

Several days after the startup of the rehabilitated lift pumps, oxygen levels stabilized at low levels. A period with high flow and no aeration began at this time and was characterized by oxygen levels below 0.5 mg/l and temperatures near 20°C. Removal efficiencies for this period are listed in Table 5. Average influent concentrations of most constituents were similar during periods of aeration and no aeration. Analyses of aeration effects were made after suficient aeration occurred to replenish

Table 5. Mean pollutant removal rates under different aeration schemes at a flow rate of 0.82 m³/s (18.8 mgd)

Parameter	Influent mean* (mg/l)	Effluent mean* (mg/l)	Removal (%)
No aeration†			
BOD₅‡	21	34	--
BOD₅	25	23	6
COD	139	91	35
TOC	40	27	32
TSS	192	32	83
VSS	76	23	69
TS	1782	1607	10
NO_3	2.21	94	57
TP	1.42	26	82
Turbidity§	97	17	83
Aeration††			
BOD₅‡	16	17	--
BOD₅	20	18	11
COD	93	58	37
TOC	41	31	24
TSS	89	34	62
VSS	42	19	54
TS	--	--	--
NO_3	3.40	3.54	--
TP	0.92	0.33	63
Turbidity§	--	--	--

* Mean concentrations.
† 5/26/79 to 6/25/79.
‡ BOD analysis using electrolytic BOD respirometer.
§ Values in JTU.
††7/7/79 to 8/7/79.

the dissolved oxygen levels in the lagoon. Removal efficiencies for the period with high oxygen and complete mixing are also listed in Table 5. Comparison of the removal rates indicates that each treatment scheme provided superior removal for certain parameters.

As shown throughout the study, the electrolytic method of BOD analysis using a respirometer (BOD_e) failed to indicate any reduction of BOD_e in the lagoon. BOD and COD showed slightly better removal rates with aeration, but removal efficiencies for all other parameters tended to be better when aerators were not operating. Without aeration, improved nitrate removal results from denitrification within zones of depleted oxygen. With aeration, induced currents limit the settling of solids, as reflected in the decreased removals.

The disadvantage of reduced detention time appears to be more than compensated by the lower degree of flow turbulence. Parameters that require lengthy reaction times and reasonable oxygen levels (such as BOD and COD) receive a greater degree of treatment under conditions conducive to complete mixing and reoxygenation. Suspended solids and the large mass of fine solids require quiescent conditions for optimal removal, as provided in the lagoon without aeration. Those parameters that are typically tied up in the solid particulates—total particulates (TP), for example—indicate similar removal rates and are therefore primarily removed by settling. Reductions in parameters such as BOD and COD, which are impeded by decreased oxygen levels, are also related to the solids fraction and thus undergo some removal by this mechanism. The data indicate that this mechanism is less effective. Optimum treatment conditions, then, would consist of a water body high in oxygen content and sufficiently quiescent to promote particulate settling. In the case of a treatment lagoon, these conditions could be achieved by using initial aeration to levels beyond the depletion capability of the wastewater and following it with a zone of quiescent flow toward the effluent to maximize settling conditions.

Removal of Heavy Metals

The inflow of heavy metals and their presence throughout the lagoon was monitored. Approximately 75 samples were evaluated for iron, cadmium, chromium, copper, lead, zinc, and mercury (Table 6). Influent lead and zinc concentrations appear to have been reduced as a result of treatment in the lagoon.

Disinfection Studies

Review of Disinfection at ECSD Facility

The original disinfection design specified chlorine as the disinfecting agent and the construction of a chlorine contact chamber at the lagoon effluent. The latter was omitted, however, and limited contact time was developed by installation of a steel weir in the effluent chamber. A high-rate chlorine/chlorine dioxide system was installed to disinfect lagoon effluent waters.

In a previously published bench-scale study,* high-rate disinfection of combined sewer overflows with chlorine and chlorine dioxide was evaluated to aid in the design and operation of full-scale treatment facilities. The report concluded that a four-logarithm reduction in indicator bacteria was obtained with dosages of 25 mg chlorine/l or 12 mg chlorine dioxide/l and a 2-minute contact time. Disinfection was enhanced beyond the expected additive effect by using sequential addition of chlorine followed by chlorine dioxide in 15 to 30 seconds. Addition of 8 mg chlorine/l followed by 2 mg chlorine dioxide/l provided reductions similar to the single dosages noted above. The ECSD disinfection system was designed on this basis.

Disinfection Program Results

The disinfection evaluation program was divided into three phases. The first phase dealt with routine bacterial monitoring of the lagoon disinfection system for dosage rates established and maintained by ECSD to meet permit requirements for the National Pollutant Discharge Elimination System (NPDES). The data collected during this period have limited practical value because of continuous malfunction of the disinfection system. The second phase consisted of a controlled set of varied chlorine/chlorine dioxide dosage experiments. This program was aimed at developing various equivalent dosage combinations for comparable fecal coliform kill effectiveness. The final phase of work was a special bench-scale study using chlorine and chlorine dioxide to augment the data deficiencies of the second phase.

Bacterial analyses of the lagoon effluent were conducted every other day during the evaluation period. Bacterial types monitored included total coliforms, fecal coliforms, and fecal streptococci. A statistical evaluation of the colony counts for each bacteria type and relationships among types was performed. Residual bacteria counts following secondary and lagoon treatment were roughly 1 percent of typical raw wastewater values, as indicated by the arithmetic and geometric means. The linear correlations among bacteria types were poor. Analysis of the t-statistic implied no correlation among the three types.

Chlorine/Chlorine Dioxide Kill Studies

The dosage experiment program began with chlorine only. Doses of 2.5 to 6.5 mg chlorine dioxide/l were added to yield background data to determine the actual chlorine dioxide efficiency during detailed evaluation of the disinfection system.

Effluent coliform levels varied widely throughout the study period, with fecal coliform colony counts ranging from 600 to 200,000 per 100 ml. This variance created difficulty in the overall evaluation, since equivalent kills, as determined on a percentage or log removal basis, would actually yield a wide range of effluent levels.

Little difference in disinfection efficieny occurred with sequential chlorine dioxide addition.

Bench-Scale Chlorine/Chlorine Dioxide Experiments

The referenced bench-scale study indicated optimum sequential dose delays of 15 to 30 seconds. The full-scale disinfection operation at East Chicago could not be analyzed under these conditions because of the fixed locations of the diffusers and limited lagoon effluent. After much data analysis, little advantage was seen with sequential chlorine dioxide addition

*Moffa, P.E., et al. Bench-Scale High-Rate Disinfection of Combined Sewer Overflows with Chlorine and Chlorine Dioxide. EPA-670/2-75-021. April 1975.

after delays of 45 to 90 seconds. A small-scale bench study was performed for this project allowing the desired sequential delay times of 15 to 30 seconds.

Chlorine was added in dosages of 1, 2, 3, and 4 mg/l, with no sequential chlorine dioxide addition. Next, sequential additions of chlorine dioxide in doses of 0.5 to 3.0 mg/l were added after 30-second delays to samples prechlorinated with 1 and 2 mg chlorine dioxide/l. Selected sequential dosage combinations were also applied using a 15-second delay period. Disinfection was greater with increased chlorine dosage. The bench study data indicate increased disinfection with sequential chlorine dioxide addition and benefits from reducing the delay period between doses from 30 to 15 seconds.

Conclusions

Results of the East Chicago lagoon evaluation clearly indicate that relatively good treatment can be provided by a deep stabilization pond. During dry weather flow periods, the lagoon provided removal capabilities of 30 to 70 percent for the secondary effluent, depending on the parameter.

The reoxygenation function of the aerators was found to be necessary. Under most circumstances, four aerators were adequate, but at times of high organic loading, the use of all eight appeared to be more advantageous. In this study, surface aeration of 0.015 hp per pound BOD applied to the lagoon per day proved to be adequate.

Disinfection results indicated that chlorination should be used until more reliable chlorine dioxide equipment is provided. The chlorine dioxide system should be reconstructed to provide extensive mixing upon initial disinfection addition, and it should provide a 15- to 30-second delay time between doses.

This work was submitted in partial fulfillment of Grant No. 11023FAV by East Chicago Sanitary District under the sponsorship of the U.S. Environemental Protection Agency.

Table 6. *Heavy metal concentrations in the lagoon*

	Influent		*Effluent*	
Metal	*Mean (µg/l)*	*Std. dev.*	*Mean (µg/l)*	*Std. deav.*
Fe	*38.3*	*198.0*	*5.3*	*12.2*
Cd	*5.9*	*6.3*	*6.9*	*22.0*
Cu	*186.5*	*220.*	*53.5*	*81.0*
Pb	*200.2*	*234.*	*79.4*	*123.0*
Zn	*603.5*	*1763.*	*120.3*	*261.0*
Cl	*107.7*	*191.*	*90.6*	*160.5*
Hg	*2.52*	*2.18*	*2.45*	*5.0*

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The complete report, entitled "Evaluation of a Treatment Lagoon for Combined Sewer Overflow," (Order No. PB 82-105 214, Cost: $11.00, subject to change) will be available only from:
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